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UNITED STATES DEPARTMENT OF AGRICULTURE
Agricultural Research Administration
Bureau of Entomology and Plant Quarantine

SAMPLING DESIGNS FOR FOREST INSECT LOSS SURVEYS IN WESTERN UNITED STATES

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INTRODUCTION

The Division of Forest Insect Investigations held an in service training conference for the western survey men at Ft Collins, Colorado, from January 15 to February 9, 1951. The purpose of this conference was to review present survey methods and objectives and to offer training in the field of survey design and the analysis of survey data. Representatives from each of the five regional field labor work s presented recent field data which served as a basis for the design of sampling methods which are to be used during the coming field season.

A sampling design was prepared for each of the following forest insects: (1) Black Hills beetle in ponderosa pine in Colorado, (2) mountain pine beetle in western white pine in Idaho, (3) mountain pine beetle in lodgepole pine in Utah (4) western pine beetle in ponderosa pine in California, (5) Engelmann spruce beetle in Engelmann spruce in Colorado, (6) spruce budworm in Oregon and Washington, and (7) aerial survey methods in the West.

It was agreed at the conference that all INTENSIVE surveys made in the future should be specifically designed so that a valid estimate of sampling ERROR would be possible. Such a plan will guarantee that each future estimate of loss will have a qualifying standard error which will indicate the relative reliability for such an estimate.

It was also agreed that a completely random sampling system, even though theoretically desirable, was not practical for most of our western survey problems. This is particularly true of loss surveys, which in addition to supplying data on loss must also supply reliable information on type boundaries. It was agreed that restricted randomization of survey lines and plots would be the essential of every survey system, with the elimination of all personal bias.

The matter of stratification of samples was a subject on which complete agreement was not possible. For some loss survey problems it was apparent that stratification yielded an improvement in efficiency, while in others no apparent gain in efficiency was noted. This is a matter which should be given further consideration and study by each field man in his particular sampling problem.

The Division of Forest Insect Investigations is responsible for conducting annual surveys of timber losses to determine the amount, intensity and trend of infestation and species of insects involved in these infestations causing such losses, to serve as a basis for recommendations for control. Unlike surveys of timber resources, which are usually made only once, surveys of insect losses must be made on an annual basis. Because they deal with a variable population and one which is subject to considerable variation between years, a survey of timber losses should be geared to recognize and take advantage of these annual variables. The intensity of coverage needed to yield a predetermined degree of precision will vary, by the precision of estimate desired, insect species, tree species infested, intensity of the infestation, character of the infestation, size of the area to be sampled, and the size and shape of sample plots.

PRECISION OF ESTIMATE DESIRED

The precision of estimate desired for any one survey will depend to a large extent on the purpose to which the data are to be used. If the data are to be used for the purpose of estimating the number of infested trees needing treatment in a control project the degree of precision may be higher than if these data are to be used to estimate seasonal trends in infestation. There is some question as to the acceptable level of error which a survey should be willing to tolerate. Usually the limitation of funds and manpower will dictate the precision of estimate possible. The general concensus of the survey men in attendance at the Mt. Collins conference was that for control projects, the maximum acceptable error to be tolerated, for small units would be 25 percent at the 68 percent level. This restriction will usually result in sampling errors of 10 percent at the 68 percent level for the whole control job which is made up of the smaller units. An example of this would be a 10,000 acre control job broken up into ten units of 1,000 acres each. If the sampling error were about 25 percent for each of the small units it would likely be about 10 percent for the 10,000 acre piece.

INSECT SPECIES AND CHARACTER OF THE INFESTATION

Knowledge of the behavior of various insect species is very important in designing a sampling system for estimating timber loss. The western pine beetle is an example of a western bark beetle which infests trees in a scattered pattern with little grouping tendency until it reaches epidemic status. At the other extreme is Dendroctonus confusus has a habit of heavy grouping tendency in very localized areas even in years of low intensity. The mountain pine beetle in lodgepole pine is an example of bark beetle which has

habits intermediate between [illegible] ster p'is beetl a d Ips The same species of insect may show v [illegible] e.nt h'bi s i [illegible] e nt species of trees and in different re[illegible] it s mparatively simple to design a survey system for the wes e n [illegible] re beetle, but very d fficult for Ips Much more information is needed [illegible] he cha acteristics f the distribution of losses by various species of bark beetles before an adequate sampling system can be set up.

INTENSITY OF [illegible] INFESTATION

It appears to be a well [illegible] lished [illegible] t that as the intensity of the infestation increas s, the p rcentag of sam l co r ge needed decreases. This is strikingly il [illegible] lated in Table , w ere for a given degree of precision it as u [illegible] y to sa p an Eng lm n pruce infestation, averaging about 60 t se n acre, by about 1.5 rcent coverage. To obtain the same degree o [illegible] ision in sampling lo se in western white pine and lodgepole pine with a verage o only abo t 0 5 trees per acre, it as necessary to sample 10 t m as much acreage

SIZE OF TH A A TO BE AMPLED

The size of an area to [illegible] mpled is probably the mos important single factor in setting up a s pling design One of the basic principles of sampling s that as the si e o the area to be [illegible] ple decreases the intensity of coverage needed in ases. Tables 1, 2, and 3 illustrate this point. Note for example, that a sampling survey des.gned to yield a 25 percent sampling error, in a la Hills beetle in e tation, it is necessary to sample 14.8 percent or 148 a s in a 1,000 acre unit Compare this with 0.8 percent or 160 acres n ded to sample 20,000 a res On a man-hour basis it would take about 16 3 m s to sample 1,000 ac o compared to only

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for timber losses caused by the Black Hills beetle. The first method was by weighted line plots composed of a number of individual 1/5-acre circular sample plots. The second method was by the analysis of the individual 1/5-acre plots. This analysis shows that the individual 1/5-acre plots give about double the precision of estimate possible with the larger line plots (see Table 1). Wherever this system of sampling is used, it is suggested that the field data be collected in such a way that it can be analyzed on both the individual plot basis as well as the larger line plot unit. This may be one way to achieve a much more precise estimate of the number of trees to be treated on a control unit.

USE OF AERIAL METHODS IN WESTERN TIMBER LOSS SURVEYS

Both Heller and Wear have demonstrated that the airplane has very definite advantages as a survey tool in estimating timber loss and damage. Further field tests and studies are urgently needed to show the possibilities and limitations of aircraft in this field. Suggested studies include loss surveys in ponderosa pine caused by the western pine beetle and the Black Hills beetle, and in lodgepole pine caused by the mountain pine beetle.

TABLE 1

Percent of Sample Coverage Needed to Yield a Sampling Error of 25 Percent at the 68 Percent Confidence Level for Losses by Several Western Bark Beetles in Different Sampling Units.

Size of Unit to be Sampled	Black Hills Beetle in P.P. 1/		Moun. Pine Beetle in W.W.P. 2/	Moun. Pine Beetle in L.P. 3/	Western Pine Beetle in P. P. 4/		Engelmann Sp. Beetle in E. S. 5/
	Percent of Sample Needed						
	(1)	(2)			(3)	(4)	
1,000	9.0	17.8	14.8	15.8	28.0	50.1	1.5
2,000	4.9	9.5	8.0	8.6	16.3	33.6	0.76
5,000	1.9	4.0	3.3	3.6	7.2	16.7	0.30
10,000	1.0	2.1	1.7	1.8	3.7	9.3	0.15
15,000	.6	1.4	1.1	1.2	2.5	6.4	0.10
20,000	.4	1.0	0.8	0.9	1.9	4.9	0.08
Ave. No. Trees/acre	0.47		0.40	0.79	0.071		60.70

1/ (1) Individual 1/5-acre circular sample plots
(2) Line Composed of 1/5-acre circular plots combined

2/ Line strips 1 chain wide

3/ Line composed of 1/5-acre circular plots combined

4/ (3) 10-acre sample plot - 10 x 10 chains
(4) 320-acre sample plot - 80 x 40 chains

5/ Line composed of 1/5-acre circular plots combined

Testing [illegible] determined
Sampling Fraction [illegible]

Number of Units to be Sampled	[illegible]	Mean [illegible]	Engelmann Sp Restl in E S.
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		(Grapos)	
000			2.4
2.000			2 5
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10			2 5
15 000			
20,000			2 5

TABLE 3

Cruising Time per Gross Acre Sampled for Different Size Units for a Predetermined Sampling Error of 25 Percent at the 68 Percent Level.

Size of Unit to be Sampled	Black Hills Beetle in P.P.		Moun. Pine Beetle in W.W.P.	Moun. Pine Beetle in L.P.	Western Pine Beetle in P.P.	Engelmann Sp. Beetle in E. S.
	Man Days per 1000 Acres in Gross Sample					
	(1)	(2)				
1,000	8.5	16.8	4.9	7.6	4.7	2.4
2,000	4.5	8.9	2.7	4.1	3.2	1.2
5,000	1.8	3.8	1.1	1.7	1.6	0.5
10,000	0.9	2.0	0.6	0.9	0.9	0.3
15,000	0.6	1.3	0.4	0.6	0.6	0.17
20,000	0.4	1.0	0.28	0.43	0.46	0.13

TABLE 4

Average Cruising Time in Acres per Man Day of Sample for Several of the Western Bark Beetles.

Insect and Host	Survey System	Acres/man day
Black Hills Beetle in ponderosa pine	Individual 1/5-acre plots.	10.6
	Line composed of 1/5-acre plots combined.	10.6
Mountain Pine Beetle in western white pine	Line strip 1 chain wide.	30.0
Mountain Pine Beetle in lodgepole pine	Line composed of 1/5-acre plots combined.	20.7
Western Pine Beetle in ponderosa pine	320-acre plots 80 x 40 chains.	106.0
Engelmann Spruce Beetle in Engelmann spruce	Line composed of 1/5-acre plots combined.	6.2

SAMPLING DESIGNS FOR SPECIFIC WESTERN FOREST INSECTS

There follows a proposed design for several of the more important forest insects in the western part of the United States, together with some suggestions for further aerial studies.

1. Survey Design for the Mountain Pine Beetle in Western White Pine -- T. T. Terrell.

2. Proposed Sampling Design for the Black Hills Beetle Survey in the Front Range Ponderosa Pine Type of Colorado -- E. P. Merkel.

3. Proposed Sampling Design for the Black Hills Beetle in Ponderosa Pine and the Mountain Pine Beetle in Lodgepole Pine Surveys, Region 4 -- R. I. Washburn.

4. Proposed Sampling Design for the Engelmann Spruce Bark Beetle in Engelmann Spruce in Colorado -- W. F. McCambridge.

5. Proposed Sampling Design for the Spruce Budworm in Oregon and Washington -- A. T. Davison.

6. Use of Aerial Methods in Western Forest Insect Surveys -- R. C. Heller.

7. Improvement of Survey Methods for the Western Pine Beetle in Ponderosa Pine in California -- R. C. Hall.

SURVEY DESIGN, FOREST INSECT SURVEYS
MOUNTAIN PINE BEETLE IN WESTERN WHITE PINE

By

T. T. Terrell

The following survey design is used to survey white pine, lodgepole pine, and occasionally other stands of timber in Region 1. The purpose of the surveys is to determine the location and numbers of trees infested by the mountain pine beetle. The design consists of continuous, chain-wide, sample strips plotted on a systematic gridiron pattern across the area to be surveyed. The strips are spaced at 20-chain intervals to obtain a 5-percent coverage or at 40 chains for 2½ percent. The results of surveys made by this design are given in the examples in the following table.

It is apparent that serious errors are likely to occur by using this type of survey in small areas unless the percent of coverage is greatly increased. An analysis of the data shows that the percent sampled in the 840-acre unit would have to be increased to 13 percent to obtain an estimate within an acceptable ± 25 percent of error. In the larger units of from 2000 acres up, 5-percent sample seems adequate. In all probability, on areas of 10,000 acres or over, even a smaller percent of sample would produce sufficiently accurate results.

The systematic gridiron design is felt to be justified over random strips because the survey is also required to locate or delineate the infested area. This can be done more accurately by an evenly-spaced gridiron system.

It is suggested that the present survey design as used in the Region 1 surveys be continued but modified to the following extent: Areas of 1000 acres or less will be planned on not less than 10 percent coverage. Where only one unit is to be surveyed, increased coverage will be planned to obtain data within 30 percent of accuracy at the 95 percent sampling level. Where several blocks are surveyed, data within ± 25 percent at the 68 percent level will be accepted.

Stands of light infestation, where close accuracy is desired, will have to be covered to approximately 10 percent.

From existing data at the Coeur d'Alene Laboratory, the degree of coverage necessary by area size and density of infestation will be worked out for future use.

TABLE 5

Yellow Dog -- Downey Units
Mountain Pine Beetle -- Western White Pine
Coeur d'Alene National Forest

Unit	Total Acres	% Sur.	Sample Acres	Inf. Trees	$\bar{Y}$ T/A	$V_{\bar{y}w}^2$	Cor. fact. $\frac{n-n}{n}$	Corrected Variance	$\bar{Y}$ SE	Total Estimate	SME %
N. Yellow Dog	840	5.6	47	14	6.30	.0149	.944	.01410	.30 ± .12	252 ± 101	40
Yellow Dog Creek	4,120	4.6	190	115	109.60	.01915	.945	.01826	.605 ± .135	2493 ± 556	22.3
Yellow Dog River	2,140	4.1	87	48	37.12	.0154	.959	.01476	.55 ± .121	1177 ± 259	22.0
Downing Creek	4,160	5.1	211	80	42.42	.0052	.949	.0049	.38 ± .07	1581 ± 291	18.4
Sissons	4,700	4.5	212	41	22.29	.0034	.955	.00325	.193 ± .057	907 ± 268	29.5
TOTALS	15,960	4.7	747	298				.00221	.40 ± .047	6384 ± 747	11.7

The data were obtained by running continuous sample strip, one chain wide, at approximately 20 chain intervals.

A SAMPLING DESIGN FOR BLACK HILLS BEETLE SURVEY IN THE FRONT RANGE PONDEROSA PINE TYPE OF COLORADO

By

E. P. Merkel

As a result of statistical analysis work, which has been initiated at the 1951 Western Forest Insect Survey School, a tentative design was developed for Black Hills beetle surveys in ponderosa pine in eastern Colorado.

All the data contained in this report was obtained from the 1950 Black Hills Beetle Survey, Roosevelt National Forest, Colorado.

Areas which were intensively surveyed were sampled, varying from 5 to 12 per cent of the ponderosa pine type.

In the survey blocks, 1/5-acre circular sample plots were taken every 2⅔ chains along cruise lines, systematically spaced 10 chains apart, through the infested type acreage.

The data from the survey field tally sheets of six surveyed blocks on the Roosevelt National Forest were analyzed statistically by two methods. The purpose of both methods was to obtain an estimate of the total number of current bark beetle-attacked trees with the standard error of estimate at the 68 percent confidence or probability level for each block and for all blocks combined.

One method of analysis was to obtain the standard error of estimate and percent accuracy by considering the individual plot-line as the ultimate sampling unit and weighting the line according to the acreage sampled by each line. The second method consisted of using the individual circular plots as the ultimate sampling unit, thus no weighting was necessary since all plots were of equal acreage.

Conclusions

Statistically, we are able to present total estimates of currently infested trees with standard error of estimates and percent accuracy of survey. Table 6 indicates that more intensive surveys are needed on small acreages and light infestations to obtain the same accuracy of estimate for large acreages of heavy infestation.

Despite considerable variation in the estimates and accuracy due to size and intensity of infestation in the different survey blocks, the over-all estimate of several infested areas falls within the limits of a much higher degree of accuracy than for individual survey blocks.

Although the present study indicates that the line-plot cruise gives a reasonably accurate estimate of the number of infested trees, considerably more attention must be given to other sampling design and until control or 100 percent cruises are undertaken on the surveyed blocks mentioned in this report, the final answer to the best sample design in ponderosa pine in this region cannot be definitely answered.

TABLE 6

Roosevelt National Forest - 1950 B.H.B. Survey
Redfeather Ranger District

Summary Chart of Estimates Based on Weighted Cruise Line Basis and Individual 1/5-acre Plots

Area	Acres	Acres Sampled	Total New Attacks	Weighted Cruise Line Basis	Individual	68% Level SME Wgt. C.L.*	SME Indv. Plot	S.E. Estimate for Indv. Plots
1A	1,216	117.4	105	1,090 ±	339	31	25	± 273
1B	1,556	78.6	25	498 ±	196	39	60	± 297
2	772	86.6	14	125 ±	65	52	35	± 44
3	1,178	145.8	69	557 ±	138	25	27	± 151
4A	1,812	115.0	56	682 ±	255	29	30	± 267
4B	2,730	119.0	912	12,503 ±	3,180	25	13	±1,583
5	500	50.0	9	90 ±	42	47	48	± 43
6	550	35.6	169	2,612 ±	745	28	22	± 580
	10,314	748.0	1,359	18,357 ±	2,352	13	9	±1,619

	Wgt. Cruise Line	Indv. 1/5-Acre Plot
Average No. of Trees/Acre	1.8168	1.8168
Standard Error	± .2327	± .1619
SME at 68% Level	12.8%	8.9%

* Individual Cruise Line

PROPOSED SAMPLING DESIGN FOR BLACK HILLS BEETLE AND MOUNTAIN PINE BEETLE SURVEYS, REGION 4

By

R. I. Washburn

Description of Survey Methods:

The survey technique employed is a line plot survey grid-ironing the desired area. In the line plot method, one fifth acre plot is taken every 2 or 4 chains depending upon the percent of sample desired. The lines run 20 chains (5% survey), or 40 chains for 2½% survey apart throughout the area.

Sampling Design:

Mountain pine beetle in lodgepole pine:

I. Heavy infestation (1 tree or more per acre)

A. Even distribution of bug trees.

A 1¼ percent survey (1/5-acre plot every four chains with the survey lines 40 chains apart) will give an estimate within a 25-percent degree of accuracy.

Example:

An analysis of the survey data for the Hoop Lake-Beaver Creek Unit, Ashley National Forest, produced an estimate of 14,960 ± 2,373 new attack trees with a SME of 15.8 percent for a 1¼-percent survey on 4,960 acres.

The 2½ percent survey analyzed by strips shows an estimated 16,016 ± 2,970 new attacked trees for a SME of 18.5 percent for the same area.

The comparison of data shows that little precision is gained by a 2½ percent line plot survey over the 1½-percent line plot survey.

B. Heavy grouping of bug trees.

The 2½ percent line plot (a 1/5-acre plot every 2 chains, one line every 40 chains) survey is required to produce a 25 percent SME.

An analysis of the 1950 survey data for four units of different degrees of infestation produced SME's of 18 percent, 22 percent, 23 percent, and 31 percent.

II. Moderate and light infestations

The 2½ percent line plot survey should produce estimates over large areas (20,000 acres or more) within allowable limits.

It is realized, that as the infestation becomes lighter, it is probable that the degree of accuracy obtained will be decreased.

III. General

The line plot survey using 1/5 acre plots is one of the desired ways to survey mountain pine beetle in lodgepole pine.

Any time the plots are closer together than the diameter of the plots (106 ft.) the total plots on each line should be considered as a single sample and analyzed the same as strip data.

When the plots are more than the plot diameter apart as in 1¼ percent surveys each plot should be considered as a separate sample.

Blacks Hills beetle in ponderosa pine, Dixie National Forest:

I. Light infestation (.5 or less trees per acre)

The analysis of the 1950 survey data for the Dixie National Forest indicated the need of further consideration of the sampling procedures.

The analysis of the Blue Fly area of 14,000 acres surveyed 5 percent by line plots gave an SME of 21.4 percent.

The use of every other line to make a 2½ percent survey indicates a 25 percent SME for the even numbered strips and 38 percent for the odd-numbered strips.

More complete data on stand density and actual bug tree location for certain areas should supply information needed to improve the sampling design for this area.

PROPOSED SAMPLING DESIGN FOR THE ENGELMANN SPRUCE BARK BEETLE IN ENGELMANN SPRUCE IN COLORADO

By

W. F. McCambridge

The following survey design is proposed for sampling losses in Engelmann spruce caused by the Engelmann spruce bark beetle in Colorado. The design consists of circular 1/10-acre sample plots located at 2-chain intervals along a continuous cruise line. For creek bottom sampling the line of plots will be taken on alternate sides of the creek bottom every five chains. The first line will always be taken to the right up 2½ chains after entering the creek bottom type. The bearing of these lines will be at right angles to the general direction of the creek flow. Plots on these lines will be two chains apart with the center of the first plot 1 chain away from the creek bed. The last plot (outside plot) will be at the edge of the creek bottom infestation, or creek bottom timber type. The stream tributaries will be treated the same as main streams (see illustration). The intensity of coverage in this type will be 5 percent.

For infestations other than creek-bottom type the same type of line plots will be used but will be established in a gridiron manner, with the location of the first line established in a random manner. For heavy infestations the sample coverage will be 2 percent, while for light infestations the sample coverage will be increased to 5 percent.

Stream

Type or Infestation Boundary

Cruise Line

A SUGGESTED METHOD OF SAMPLING INTENSIVELY A PORTION OF THE 1951 SPRUCE BUDWORM CONTROL AREA IN OREGON AND WASHINGTON

By

A. T. Davison

During the summer of 1951 it is planned to spray 1,012,740 acres of forest lands in Oregon and Washington in order to hasten the control of the spruce budworm on the true firs and Douglas firs. If the Portland station is to be required to give exact mortality figures for the control job, a relatively expensive and involved sampling procedure appears required. The first apparent fact is that the total area could not be covered adequately unless the entire project was set up on an experimental basis and a large force of men were retained to carry out just that one phase of the project. In a control job of this size, such an undertaking would hardly be possible. Then the objective must be to intensively sample a small portion of the total, and use the results of this sampling as one indication of the efficacy of the control operation. The use of spray deposit plates well dispersed throughout areas not covered by the intensive sampling to insure adequate spray dispersal and strict enforcement of regulations covering equipment and methods should insure that the mortality on these areas would be comparable to that found on the areas covered by the mortality sampling system.

The primary conditions requiring consideration in the sampling design are: (1) the two forest types found, that is, the east side stands and the western Oregon forests, (2) the use in the project of two widely different types of aircraft, the small trainer planes and the large cargo

planes, and (3) the use of several contractors on the control job. Secondary conditions would be such matters as topography, altitudes, and composition of stands.

Once the units have been designated with the above conditions in mind, the sampling design could be undertaken fairly mechanically. First, a series of spray blocks from each unit would be chosen at random, with the condition that they be accessible. Within each block at least two sampling lines traversing the entire block would be designated on aerial photographs. These lines would be placed in the block so as to cut across the designated flight pattern. Starting 5 chains in from one boundary, sampling stations would be taken at ten-chain intervals along the line by the field crew establishing the line before spraying. These lines and stations would be marked so that after larval drop has finished, the same stations would be revisited. At each sampling station ten 15-inch terminal twigs would be collected with the use of pole pruners and basket and the larval population recorded. If for any reason the station should fall in some area when the forest type inhibited the collection of samples, the station would be established at the closest point to the desired one. If the station fell along a road or other stand disturbance it would be either dropped or placed at a reasonable distance from the disturbance. On returning to the stations after the completion of spraying, 20 samples would be taken, and the population of live budworm and pupae would be recorded.

The lines could best be run by two man crews, and it is estimated that each crew could establish 3 miles of line per day. The crew would require transportation, tatum holders, a pole pruner equipped with a catching basket, compasses, a sheet of cloth upon which to count larvae, a cruiser's axe to mark the line and the sampling stations, keel for

numbering the stations, dissecting needles, and tally registers. Chaining the distance would be by pacing, and if possible, the stations would be located on aerial photographs as they were established.

In the small blocks used in the units sprayed by the trainer type planes, two lines per block would usually suffice. These blocks are ordinarily about 1000 acres in size. On the larger blocks used when the cargo type planes do the spraying, more lines per block would be needed. The number would depend on the size and shape of the block.

The need of at least two lines in a block is suggested so that the data received can be analyzed on a statistical basis. If the station is to give out figures of percent of mortality, it is hoped that a sound statistical backing will make them more real.

A SUGGESTED DOSAGE-MORTALITY STUDY TO BE CARRIED OUT IN THE 1951 SPRUCE BUDWORM CONTROL PROGRAM

By

A. T. Davison

In order to ascertain the minimum actual dosage of DDT spray needed to give a satisfactory larval mortality in the Oregon-Washington spruce budworm control program of 1951, it was stressed by MacAloney and Waters that a dosage mortality study be undertaken on one of the control units during the 1951 season. The importance of a knowledge of the actual range of dosage delivered to the forest canopy cannot be overemphasized in the light of the use of a 3/4 lb/gallon dosage in the control operation.

The dosage-mortality study for the forthcoming project should be designed very closely after the one made in Maine during the summer of 1950, making use of the larval drop system of insect sampling. In the unit decided upon selection of at least 50 trees chosen at random that would fit the requirements for the study would be necessary. These trees should be about seventy feet tall, in open enough stands so that dosage plates could be elevated around the crown without interference from adjacent trees, and be reasonably accessible.

The larval drop method of sampling spruce budworm mortality is outlined in the report of January 19, 195 by Waters, Marsh and Heller.

USE OF AERIAL METHODS IN WESTERN FOREST INSECT SURVEYS

By

R. C. Heller

Some of the aerial surveying methods which might be used to supplement ground surveys are outlined below. These are merely suggested procedures which might work on reconnaissance and appraisal surveys.

I. Bark-beetle Damage

A. Aerial strip viewing

1. Location of strips

a. Between recognizable landmarks if possible

b. Number of strips (or total mileage on strips) dependent on percentage of sample desired

2. Use operation recorder to determine number and location of infested trees along strip

B. Sketch mapping on existing photos and planimetric maps

1. Locate infested stands with fair accuracy

2. Reduce ground survey work by localizing infestations

C. Aerial Photography

1. Location of strips - same as for strip viewing above.

2. Advantageous only if it produces better accuracy.

a. May be useful on dense stands of lodgepole pine.

b. Can be studied in office and reliable area estimates made if scale is accurately determined.

c. Color photography may detect early fading before it is positively recognizable by ocular viewing.

II. Defoliator Damage

A. Visual Surveying

1. Aerial strip viewing.

a. Vertical strips

b. Lateral strips

2. Sketch mapping on small scale maps.

a. Cover large areas rapidly

b. Determine approximate size and location of heavy outbreaks.

On all bark-beetle aerial surveys it appears that a limited amount of ground sampling will be necessary to arrive at a percentage or ratio of green but dead trees to dead discolored trees. Since all aerial surveying is predicted on a change in color, this ratio has a true value over a given area and can be estimated. The amount of sampling required to get a reliable estimate of this ratio for any accuracy can be calculated after preliminary plots are taken. Naturally, the ratio will vary from year to year according to fluctuations in the beetle population but the number of plots to be taken should remain constant. Thus, by applying the ratio to the currently discolored trees, we may be able to produce an aerial survey which comes within acceptable accuracy limits and allows us to cover more area at a cheaper cost.

A DESIGN FOR SAMPLING DRAIN N PINE IN THE CALIFORNIA REGION

By

Ralph C. Hall

From basic, annual survey data collected in the Burney area over an eleven-year period, it appears possible to obtain rather reliable data of drain figures in pine. The survey system used in this area was a combination of 20-acre permanent sample plots supplemented by a series of road-side plots which together constituted about a 3 5 percent sample coverage of about 170,000 acres of virgin pine. This study was set up with the objective of obtaining annual loss figures which would be subject to about 15 percent sampling error at the 95% level. During the eleven-year period the average sampling error proved to be about 16.2 percent which is very close to the expected goal (Figure 1 and Table 7). Note from this figure that the principle, mentioned earlier, seems to hold that as losses are reduced, sampling error is increased.

This study also demonstrated that the sampling error was reduced about half for the estimate of loss based on the average for the eleven-year period. Another very interesting thing which resulted from this study was the relative reliability of the 20-acre plots for estimating loss for the average for the eleven-year period. It was shown that 34 twenty-acre plots or only about four tenths of one percent coverage, yielded drain data which had a sampling error of only 16.2 percent at the 95-percent level. The estimated average annual loss for the 11-year period, obtained from both the twenty-acre plots and the strips, was 81 board feet per acre plus or minus 6.2 board feet at the 95-percent level. The estimated loss for the

same period, obtained from the 20-acre plots alone was 88 board feet plus or minus 14.4 board feet per acre at the 95-percent level. This later sample represented only four-tenths of one percent of the total area.

The information gained during the past 11 years, in sampling losses in the Burney area, indicates that it is possible to obtain drain figures in pine in which considerable confidence can be placed. From the practical standpoint, if it is only cumulative drain information that a timber-land owner desires, it probably would be more efficient to collect these data from a series of plots of ten or twenty acres in size, which would be cruised about once in ten years. If it is annual drain information which a timber-land owner desires, then the road-side strip or long narrow trail strip should be used.

To assume a problem where drain information is desired on a National Forest, we might take the Lassen Forest as an example. This forest now has about 600,000 acres of virgin timber remaining. Assume a sampling error tolerance of 15 percent at the 95-percent level, then about 7,000 acres or about 1.2 percent of the area would need to be covered to furnish a reliable estimate of annual losses. If drain information was desired on a ten-year cumulative basis, it would then be necessary to sample only about 700 acres in twenty-acre sample plots. This would represent only about one tenth of one percent coverage, to achieve the same degree of accuracy.

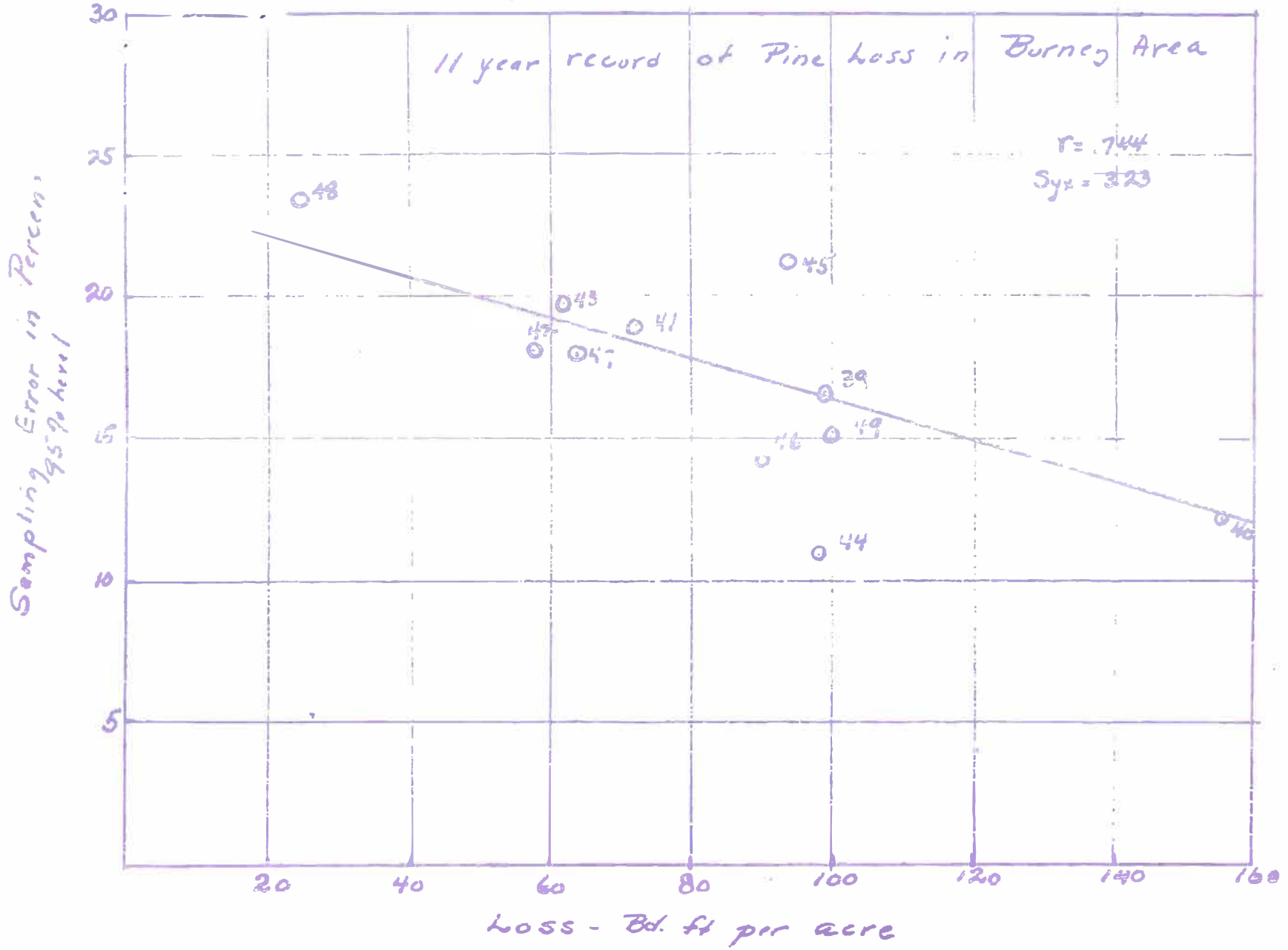
Further information is urgently needed at the Berkeley Laboratory on the type and intensity of survey coverage needed to estimate the number of trees and volume needing treatment on a recommended control area. It is suggested that a study, of size and shape of plots best suited for this purpose, be undertaken at Blacks Mtn. during the coming field season. A 100-percent coverage is already planned for about 5,000 acres of this area and this would furnish an ideal basis of actual loss with which to compare estimated losses by various systems which should be investigated.

TABLE 7

AVERAGE ANNUAL LOSS IN PINE IN THE BURNEY AREA FOR A 11-YEAR PERIOD, WITH STANDARD ERROR AND SAMPLING ERROR

Year	Annual Loss Bd. ft./acre	Standard Error Bd. ft.	Sampling Error in Percent 68% Level	95% Level
1939	94	± 7.8	8.3	16.6
1940	155	± 10.3	6.6	13.2
1941	73	± 7.0	9.5	19.0
1942	58	± 5.2	8.9	17.8
1943	62	± 6.2	10.0	20.0
1944	96	± 5.2	5.4	10.8
1945	93	± 10.0	10.7	21.4
1946	91	± 6.6	7.2	14.4
1947	65	± 5.7	8.7	17.4
1948	26	± 3.1	11.9	23.8
1949	100	± 7.5	7.5	15.0
Ave./year	81	± 6.6	8.1	16.2
Ave. for 11-yr. period all samples (5910 acres)	81	± 3.1	3.8	7.6
Ave. for 11-yr period 20-acre plots alone (680 acres)	88	± 7.2	8.1	16.2

Fig 1


11 year record of Pine Loss in Burney Area
r = .744
Syx = .323
Sampling Error in Percent, 95% Level
Loss - Bd. ft per acre
30
25
20
15
10
5
20
40
60
80
100
120
140
160
48
45
43
41
47
47
39
49
46
44
40

GLOSSARY OF STATISTICAL TERMS AND FORMULAE USED IN SAMPLING

y = Individual sample observation.

n = Number of individual observations recorded.

N = Infinite population, total number of sample units possible.

$\sum_S^n$ = Sum of n quantities.

$\sum_S^n(y)$ = Sum of n individual observations.

$\bar{y}$ = Mean of individual observations.

$(y - \bar{y})$ = Residual, or deviation from mean.

$\sum_S^n(y^2)$ = Sum of individual squared observations.

$\sum_S^n(y)^2$ = Sum of individual observations squared.

CT = Correction term = $\bar{y}\left[\sum_S^n\right]$ or $\frac{\left[\sum_S^n y\right]^2}{n}$

SS = Sum of squares = Any one of the following formulae.

1. $\sum_S^n(y^2) \quad \bar{y}\left[\sum_S^n(y)\right]$

2. $\sum_S^n(y^2) - \frac{\left[\sum_S^n(y)\right]^2}{n}$

3. $\sum_S^n (y - \bar{y})^2$

DF = Degrees of freedom = $n - 1$

V = Variance

w = Weight

yw = Weighted individual observation

To determine V when all sample lines are of equal length

V (y) = Variance of the sample. = $\frac{\left[\sum_S^n(y^2)\right] - \bar{y}\left[\sum_S^n(y)\right]}{1}$

V ($\bar{y}$) = Variance of the mean of the sample = $\frac{\left[\sum_S^n(y^2)\right] - \bar{y}\left[\sum_S^n(y)\right]}{n(n-1)}$

$V \sum_S^n(y)$ Variance of the sample sum. $= \dfrac{\left[\sum_S^n (y^2) - (\bar{y}) \sum_S^n (y)\right] n}{n-1}$

When the sample lines are of unequal length, or if there is some other reason that weighting is necessary, the following formulae are to be used.

$V(yw)$ Variance of the weighted sample: $\dfrac{\sum_S^n \left[w(yw)^2\right] - (\bar{yw}) \sum_S^n \left[w(yw)\right]}{n-1}$

$V(\bar{yw})$ Variance of the weighted mean: $\dfrac{\sum_S^n \left[w(yw)^2\right] - (\bar{yw}) \sum_S^n \left[w(yw)\right]}{\sum_S^n (w)\,(n-1)}$

$V \sum_S^n (yw)$ Variance of the weighted sample sum: $\dfrac{\left\{\sum_S^n \left[w(yw)^2\right] - (\bar{yw}) \sum_S^n \left[w\,(yw)\right]\right\}\left\{\sum_S^n (w)\right\}}{n-1}$

$\left(1 - \frac{n}{N}\right)$ or $\left(\frac{N-n}{N}\right)$ = Correction term for finite population. This term is always applied at the variance level. The correction term is the proportion of the total population not sampled. For example if a 5% cruise were run, 0.95 would be the correction factor.

$V\left(\bar{y} - \frac{n}{N}\right)$ = Variance corrected for finite population.

SD or σ = Standard Deviation $= \pm\sqrt{V(y)}$

SE $(\bar{y})$ Standard Error of the mean of the sample $= \pm\sqrt{V(\bar{y})}$

SE $\left[\sum_S^n (y)\right]$ Standard Error of the sample sum $= \pm\sqrt{V\left[\sum_S^n (y)\right]}$

SME Sampling error expressed in percent $= \dfrac{SE(\bar{y})\,(t)}{\bar{y}}$: at the 68% level t = 1
at the 95% level t = 2

When n is a number less than 20 the value of t should be looked up from the table of t in Shumacher &Chapman, page 42.

To Determine the number of samples needed in an area to obtain a desired degree of precision.

$$n = \frac{(N)(Vy)}{(N)\left[(\bar{y})\left(\frac{SME}{t}\right)^2 + (\bar{Vy})\right]}$$

Problem: (1) to determine the number of 20 acre sample plots needed to yield a sampling error of 10% in a unit of 10,000 acres, at both the 68 and 95 % levels.

$\bar{y}$ = 245 bd. ft. per acre $(Vy) = 51,475$, $(N) = 10,000/20 = 500$

At the 68% level

$$n = \frac{(500)(51,475)}{(500)\left[(245)\left(\frac{.10}{1}\right)^2 + 51,475\right]} = 73 \text{ plots or } 14.6\% \text{ sample.}$$

At the 95% level

$$n = \frac{(500)(51,475)}{(500)\left[(245)\left(\frac{.10}{2}\right)^2 + 51,475\right]} = 203 \text{ plots or } 40.6\% \text{ sample.}$$

Problem (2). To determine the num[illegible] acres of st[illegible] which [illegible]uld sampled in a 10,000 c[illegible] lock f[illegible]we tem whi[illegible] to yie[illegible] a sampling rro[illegible] of 2[illegible] t the [illegible]% level

$\bar{y}w$ (mean number of t[illegible]e[illegible] per acre) 0.7862
V(yw) Variance of [illegible]u[illegible]ed sampl[illegible] 7.599
N total number of acr[illegible]in b[illegible]ock to be sampl[illegible]

$$n = \frac{(N)(Vyw)}{(N)\left[\frac{(\bar{y}w)(SME)}{t}\right]^2 + (Vyw)} \qquad \frac{(10[illegible])(7.599)}{(10,0[illegible])(.7862)(.25)]^2 + 7.599}$$

[illegible]9 acr[illegible] t[illegible] 93% [illegible]mpl[illegible] t[illegible] 68 [illegible] vel

Problem (3). To [illegible]llust[illegible]ate the [illegible]st[illegible] dete[illegible]ining samp[illegible] [illegible]ur wa[illegible] [illegible]ea[illegible] in the strip[illegible] a[illegible]e[illegible]n t[illegible] [illegible] (Weig[illegible]ting)

Data Sheep Mt., Clearwater N[illegible] F[illegible]. d[illegible] Tom Ter[illegible]. [illegible]l[illegible] D[illegible]ta
Acres in the Unit Sampled [illegible]. t[illegible] s[illegible]mp[illegible] [illegible]or l[illegible] a[illegible]e[illegible] in strips

Strip	w Acres	y Trees	yw Trees per Acre	yw)	w(yw)
1	11	5	0.4545	5	2.7[illegible]
2	16	11	0.6875	1[illegible]	7.5625
3	19	11	0.5789	11	6.3679
4	18	17	0.9444	[illegible]7	6.[illegible]3[illegible]
5	17	42	2.4705	[illegible]2	103.7[illegible]
6	17	[illegible]8	1.05[illegible]	18	19.[illegible]
7	17	6	0.3529	[illegible]	2.1[illegible]
[illegible]	16	2	0.1250	[illegible]	0.2500
9	7	2	0.2857	[illegible]	0.[illegible]71[illegible]
10	7	0	0	0	
SUM	145	114		[illegible]4	1[illegible]8.0159
	$\sum_s^n (w)$			$\sum_s^n (yw)$	$\sum_s^n w(yw)$

$n = 10$ $\quad \bar{y}w = \frac{\sum_s^n w(yw)}{\sum_s^n (w)} = \frac{[illegible]}{[illegible]} = .7862$ trees per acre

$$V(\bar{y}w) = \frac{\sum_s^n \left[w(yw)^2\right] - (\bar{y}w)\left[w(yw)\right]}{\sum_s^n (w)(n-1)} = \frac{158.0159 - (.7862)(114)}{(145)(9)} = \frac{68.3891}{1305}$$

$= .0524\ (.95) = .04[illegible]$ corrected for finite population

$SE(\bar{y}w) = \pm\sqrt{.04978} = \pm .23$

$SME = \pm \frac{0.283\ (t)}{.7862} = 2.4\%$ at the 68% level

Estimated total popula[illegible] [illegible]stimated [illegible]ees [illegible] 2,[illegible]20 acres

(0.7862 trees per acre [illegible]ou acres) = 2[illegible] trees ± 647 trees

Steps Used in Estimating Population Totals

1 To determine the total area for which no census figure is obtainable. This may necessitate a preliminary survey.

2 A preliminary survey of a sample area is made. From preliminary or of past data, a density figure is determined. This density figure per unit area is then applied to the sample observations made.

3 To determine the number of sample units needed. From the data gathered in Steps 1 and 2, the number of sample units required to give an estimate of the desired precision is computed.

4 The survey is run.

5 Tabulation and summation of the observations for each of sample plot or strip is made.

6. Determination of the mean.

7. Squaring of the individual observations.

8. Summation of the individual squared observations.

9. Computation of the variance about the mean.

10. Correction of the variance for the finite population.

11. Determination of the standard error of the mean.

12. Raise the mean and its standard error or the standard error to an estimate of the total population or unit.

In the case of stratified data, these steps are followed within each block and the estimate of the total population for the survey unit is obtained by a summation of the individual populations, and a new standard error is found.

13. Calculation of the sampling error.